

PROCESSING OF IMAGES USING A LIMITED NUMBER OF BITS

Cross-Reference to Related Applications

- 5 This application claims priority under 35 USC §119 to Finnish Patent Application No. 20030045 filed on January 13, 2003.

Field of the Invention

- 10 The present invention relates to a method for processing images, in which method the number of bits per pixel is limited, wherein the pixel is encoded with the limited number of bits. The present invention also relates to a system for image processing, which system is arranged to process the image using a limited number of bits in the bit sequence per pixel, wherein the system also
15 comprises means for encoding the pixel to the limited number of bits. Furthermore, the present invention relates to a device for image processing, which device is arranged to process the image using a limited number of bits in the bit sequence per pixel, wherein the device also comprises means for encoding the pixel to the limited number of bits. The invention also relates to a
20 computer software product for image processing. The invention also relates to a camera module and a circuit comprising an encoder and a decoder. Furthermore, the invention relates to a device for image processing, which device comprises a decoder.

Background of the Invention

- Digital cameras comprise semiconductor cells, such as CCD (Charge Coupled Device) or CMOS (Complementary Metal-Oxide Semiconductor) cells comprising a photosensitive sensor. The operation of the sensor in the
30 cell is based on the principle that it is always charged when radiation impinges on it. The cell comprises densely placed parallel pixels which convert light to electrical signals. For colour detection, the pixels of the cell are covered by a filter which transmits, at certain pixels, only red colour, only green colour and only blue colour, respectively, forming a colour filter array. There is a given
35 number (N) of bits per each pixel. If the data processing unit is capable of processing images of M bits and if $N > M$, a conversion of the image to a

smaller size is needed, which means a reduction in the number of bits per pixel.

5 Normally, the number of bits per pixel is 8 bits, but there are cases in which a greater number is used, for example 10 bits per pixel. Normally, in a data processing device, one byte consists of 8 bits; therefore, it will be necessary to compress an image of 10 bits.

10 Furthermore, the compression of the image is necessary, because the digital reproduction and processing of images is no longer limited to computers but, to an increasing extent, images can be produced and displayed with smaller devices, such as, for example, mobile communication devices. In mobile communication devices, the use of images is largely similar to the use in computers. Images are stored in the device and they are transmitted to
15 another device across a communication network in use. The transmission of images in the communication network, such as a mobile telephone network, is problematic because of the large quantity of information. Because the available communication channel is slow, the image material must be compressed so that several minutes would not be taken for the transmission
20 of a single image.

DPCM (differential pulse code modulation) is a known method, by which a pixel is encoded / transmitted on the basis of the preceding pixel. The method is used for the conversion of an analog signal to a digital signal, wherein the
25 difference between a sampled value of the analog signal and its predicted value is quantized and encoded in digital format. Code words formed by the DPCM method represent differences between values.

30 By differentiating the pulse code modulated (PCM) code words, a DPCM code word sequence of variable length is obtained, which normally compresses the given data to a format suitable for the transmission. Because the code words are normally of variable length, the result is not always necessarily below the predetermined bit number (M), because the longest code word is longer than the original number (N) of bits. To make sure that the code word is shorter
35 than the limit value (M), the DPCM code words must be quantized, after which the compression method becomes lossy.

This problem is discussed in the publication DE 4210246 A1 which discloses a DPCM image codec supplemented with PCM technology. A questionable method is used to reduce the quantity of data in a digital image. In the method, the process of encoding digital data is used to convert the data with M bits per pixel to a code word of N bits, when $N < M$. The choice between the PCM and DPCM methods is made with respect to the difference values in the grey level. The decoding process is used to make sure that the length of the produced code word is less than 9 bits, but this code word length is not fixed but it varies according to the grey level changes in the image. The method presented in the publication is based on a state machine which will require control signals to operate. The decoding of the pixels of varying length is thus strongly dependent on other pixels. Another problem in the decoding of pixels with varying length according to related art is that it is not easy to determine from the code stream, which pixel each code represents.

Summary of the Invention

The aim of the present invention is to provide an improved method for compressing image data, in which the location of each encoded pixel can be determined independently. This is possible in that the code words have a fixed length, wherein no separate signals will be needed to indicate the initial point of the next code word. By the method of the invention, each image line can also be encoded and decoded independently. This is possible, because no pixel will need information about other pixels on another line. By means of the invention, high-quality compression is achieved for raw data of N bits for its transmission to an image processing module of M bits ($M < N$). By means of the invention, pixels in an image can be encoded quickly and with little memory capacity without affecting the quality of the image to a noticeable degree.

To achieve the above-mentioned aims, the method according to the present invention is primarily characterized in finding a prediction value corresponding to said pixel. If the prediction value is found, the difference between the pixel and the prediction value is determined, wherein the difference is used to select the encoding method to be used for encoding the bit string of said pixel,

wherein the encoded bit string with a fixed length also comprises a code word indicating the encoding method selected for the pixel.

5 The image processing system according to the invention is characterized in that the system is arranged to search for a prediction value corresponding to said pixel. If the prediction value is found, the system is arranged to determine the difference between the pixel and the prediction value, wherein the means for encoding the pixel are arranged to apply the method corresponding to the difference for encoding the bit string of said pixel as well as to encode, in the
10 bit string, also a code word to indicate the selected encoding method in such a way that the encoded bit string has a fixed length.

The device according to the invention is characterized in that the device is arranged to search for a prediction value corresponding to said pixel. If the
15 prediction value is found, the device is arranged to determine the difference between the pixel and the prediction value, wherein means for encoding the pixel are arranged to apply the method corresponding to the difference for encoding the bit string of said pixel as well as to encode, in the bit string, also a code word to indicate the selected encoding method in such a way that the
20 encoded bit string has a fixed length.

The computer software product according to the invention is characterized in that the storage means of the computer software product comprises computer instructions to search for a prediction value corresponding to said pixel, computer instructions to determine the difference between the pixel and the
25 prediction value, computer instructions for encoding the pixel by the encoding method indicated by the difference, as well as computer instructions to encode the code word representing the encoding method indicated by the difference, in such a way that the encoded bit string has a fixed length.

30 The camera module according to the invention is characterized in that the camera module comprises means to search for a prediction value corresponding to the pixel, wherein the camera module comprises means to determine the difference between the pixel and the prediction value, wherein
35 the means for encoding the pixel are arranged to perform the encoding of the bit string of said pixel by the encoding method indicated by the difference as

well as to encode, in the bit string, also a code word to represent the encoding method indicated by the difference, in such a way that the limited bit number is fixed to substantially all the encoded pixels of the image.

5 The circuit according to the invention is characterized in that the encoder comprises memory means for storing the pixel as a prediction value, wherein the encoder is arranged to retrieve the prediction value corresponding to the pixel from said memory means. The encoder also comprises means for determining the difference between the pixel and the prediction value, wherein
10 the encoder is arranged to encode said pixel by the encoding method indicated by the difference, as well as to encode, in the bit string, also a code word to represent the encoding method indicated by the difference, in such a way that the limited number of bits is fixed to substantially all the encoded pixels of the image.

15 The device according to the invention, comprising a decoder, is characterized in that the decoder is arranged to recognize the code word in the bit string and to decode the pixel by the encoding method indicated by the code word. The decoder also comprises storage means for storing at least one decoded pixel
20 as a prediction value, wherein the decoder is arranged to retrieve the prediction value corresponding to the pixel from said storage means.

In other words, in the invention, minor changes between pixels are encoded with a differential pulse code, wherein major changes between pixels are
25 encoded with a pulse code. In the method according to the invention, no control signals will be needed to select the method for decoding the pixel, wherein each pixel can be decoded independently. This is achieved in that the bit format at the beginning of the bit string indicates the decoding method to be used. The encoding system is formed in such a way that the bit resolution
30 decreases gradually more slowly than the number of colours increases in each encoding alternative. The quality of the image is not affected in the method, because the bit format indicating the last encoding method is the shortest of all, wherein more bits are left for encoding of the colour value than in the other alternatives. However, in proportion to the number of colours,
35 there are fewer bits.

By the present invention, the process for encoding pixels becomes faster and, furthermore, the method of the invention requires less memory capacity than methods of related art. The image produced according to the invention is of a better quality than images produced by the lossy methods of related art. In the method, fixed code words are formed which are easier to decode and which guarantee an output suitable for transmission. The codec according to the invention is simple to implement, and it does not require large buffers, because less buffering can be used in connection with fixed code words, or no buffering is needed at all.

Description of the Drawings

In the following, the invention will be described in more detail with reference to the appended drawings, in which

Fig. 1 shows an advantageous example of an encoder/decoder according to the invention, implementing a 10 - 8 - 10 bit conversion, and

Fig. 2 shows another advantageous example of an encoder/decoder according to the invention, implementing a 10 - 7 - 10 bit conversion,

Fig. 3 shows a device performing encoding and/or decoding of an image according to a particularly advantageous embodiment of the invention, and

Fig. 4 shows a flow chart of the operation of the encoder according to a particularly advantageous embodiment of the invention.

Detailed Description of the Invention

In the more detailed description of the invention, the following variables will be used:

Xorig to determine the original pixel value (e.g. 10 bits),

- Xpred to determine the predicted pixel value,
Xdiff to determine the difference between the original and predicted
 values ($X_{\text{orig}} - X_{\text{pred}}$),
Xenco to determine the encoded pixel value (e.g. 8 bits), and
5 Xdeco to determine the decoded pixel value.

The basic idea of the invention is that if the prediction is sufficiently good, that is, the difference between the original and predicted pixel values is smaller than a predetermined limit value ($\text{abs}(X_{\text{diff}}) < \text{Lim}$), the difference value is
10 transferred, in quantized format, to the DPCM codec. Otherwise, the original value is transferred, in quantized format, to the PCM codec. Information about the selected codec is also transferred in connection with said values. In both methods, a fixed number (M) of bits is used to represent one pixel. The bit
number M is determined according to the capacity to be used.

15 In an advantageous embodiment of the invention, an example of a 10-bit colour image is processed, which is compressed to 8 bits for the time of image transmission and processing. Figure 1 shows an advantageous
embodiment of an encoder/decoder implementing the method. In addition,
20 Table 1 below shows the encoding of a pixel as an example. In the table, fourteen pixels of a random pixel line are collected, which are encoded by the method according to the invention. The table shows the original pixel (X_{orig}), the prediction value (X_{pred}) corresponding to the original, the difference
(X_{diff}) between the original pixel and the prediction value, the encoded bit
25 string (X_{enco}) of the pixel, and the decoded pixel (X_{deco}). In the example in the table, the original pixel (X_{orig}) consists of 10 bits and is encoded to a pixel of eight bits (X_{enco}). The encoded bit string (X_{enco}) is further decoded to 10 bits by the method according to the invention. Naturally, the presented
values are only examples and they shall not be interpreted to restrict the
30 invention.

Xorig	Xpred	Xdiff	Xenco	Xdeco
302	Not available		01001011	302
120	Not available		00011110	122
156	302	-146	1 0010011	156

90	122	-32	010 1 0000	90
135	156	-21	00 1 10101	135
94	90	4	00 0 00100	94
154	135	19	00 0 10011	154
118	94	24	00 0 11000	118
235	154	81	011 0 0100	235
98	118	-20	00 1 10100	98
137	235	-98	011 1 1000	138
90	98	-8	00 1 01000	90
138	138	0	00 1 00000	138
88	90	-2	00 1 00010	88

Table 1.

- 5 In an advantageous embodiment of the invention, one pixel is used for prediction, wherein the value on the left hand side of the pixel is used as the prediction value (Xpred). If there is no prediction value available, that is, in a situation in which the two first pixels of an image line are processed, the original pixel is quantized from N bits to M bits and is transferred to the PCM codec. In a second advantageous embodiment of the prediction, more pixels
- 10 can be used, for example three pixels, wherein the prediction value is evaluated from three pixels (upper, left, upper left pixels) adjacent to a pixel. The three-pixel prediction is preferably implemented in a way presented in the applicant's Finnish patent application No. 20000131. This kind of a prediction will give a better final result in the invention, but it will require more memory
- 15 capacity than prediction by one pixel and it will eliminate the possibility to encode and decode each image line independently. For this reason, the more detailed description of the invention will focus on the prediction using one pixel.
- 20 The image is encoded in such a way that the same line method is used for encoding each line in the image. The encoding principle according to the invention, for one line, is illustrated in the flow chart of Fig. 4. From the Bayer matrix image, which is the best known form of said colour matrix (CFA), it is known that the data of a colour image is represented in such a way that
- 25 between two identical colour components on the same line, there is another

colour component (for example, GRGRGR or BGBGBG, with red R, green G, blue B). On the basis of this information, the prediction can be implemented in such a way that in the prediction of a pixel $X(n)$, the preceding decoded pixel of the same colour is used, wherein, in other words, the pixel $X(n-2)$ preceding the preceding one is used, which is, consequently, of the same colour as the pixel $X(n)$. Naturally, there is no preceding value (to be used in the prediction) for the first two pixels at the beginning of an image line, wherein the original value is quantized.

10 $X_{enco}(0) = X_{orig}(0) / 4$

The reason for using number four as a quantizer is that, in the example, the value is to be compressed from 10-bit data to 8-bit data ($1024 / 256 = 4$). If $X_{enco}(0) = 0$, the value 1 (00000001) is transferred, to avoid the code word '0' (00000000). The decoded code word can be formed as follows:

$X_{deco}(0) = 4 \times X_{enco}(0) + 2$, in which the number two is added for rounding.

20 The second pixel $X_{orig}(1)$ is processed accordingly ($X_{enco}(1) = X_{orig}(1) / 4$), because it is of a different colour than the pixel $X_{orig}(0)$.

25 To encode the third pixel ($n = 2$), a prediction will be needed, for which the decoded value of the same colour, preceding the pixel in question, is used, to obtain the prediction value for the third pixel $X_{pred}(2) = X_{deco}(2-2)$. In the general format, the prediction value is obtained $X_{pred}(n) = X_{deco}(n-2)$, when n indicates the location of the pixel. The change (difference) in the pixel can be determined by calculating $X_{diff}(n) = X_{orig}(n) - X_{pred}(n)$.

30 If the absolute value of the change between the pixel in question and the prediction value is sufficiently small (< 128), the DPCM codec will be used in the encoding. If the absolute value of the change between the pixel in question and the prediction value is high (> 127), the PCM codec will be used in the encoding (to be described in more detail under section (1) below).

35 The encoded bit string comprises, in the beginning, a code word, from which the magnitude of the change is detected (00, 010, 011 ; < 32 , 32 to 63,

64 to 127, respectively). The length of the code word corresponds to the lengths of Huffman code words, which are 1, 2, 3 and 3. The code word with the length of one is reserved for the symbol indicating escape from the encoding method, which should be either "0" or "1". Preferably, the code word for the escape symbol is "1", because thereby the second smallest code word, having a length of 2, can be selected to be "00". As the reason for the choice can be given the fact that it is thus possible to avoid the complete code word "00000000" when the difference zero is transmitted as the value -0, that is, "00 1 00000". In this way, the complete code word "00000000" does not need to be avoided elsewhere, because the other code words contain at least one "1" in them. When the second code word is selected to be "00", the code word with the length of one must be "1" to make the decoding unambiguous. Because of the unambiguous decoding, the other two code words are thus "010" and "011". If the use of the complete code word "00000000" did not need to be avoided, the code words could naturally be also, for example, "0", "10", "110" and "111". It should be noted that sometimes there may also be a need to avoid other complete code words, such as, for example, "11111111", wherein there may be a need to change the code words. Consequently, the choice of the code words is not restricted to the code words mentioned in the description.

After the code word, one bit is reserved for the sign, because the change between the pixels may be negative. The remaining bits give the change value in a binary representation. In the decoding process, in a corresponding manner, the decoder recognizes the code word at the beginning of the bit string, to select the method to be used for decoding. In the decoding, the pixel value is determined by using the preceding value of the same colour, already decoded, ($X_{pred}(n) = X_{deco}(n - 2)$) as well as the change that was between the original pixel and the preceding pixel of the same colour (value = $X_{diff} = X_{orig}(n) - X_{pred}(n)$). The pseudo code below represents a codec implementing the coding/decoding process for each range of change:

DPCM1:
if abs($X_{diff}(n)$) < 32, **then**
 $X_{enco}(n) = "00 \text{ s } xxxxx"$
 $X_{deco}(n) = X_{pred}(n) + \text{sign} * \text{value}$

5 in which 00 is the code word, s represents the sign, and "xxxxx" indicates, in five bits, the value = $\text{abs}(\text{Xdiff}(n)) / 1$, the quantizer being 1. For example, when $\text{Xdiff}(n) = -9$, the coded value $\text{Xenco}(n) = "00\ 1\ 01001"$

DPCM2:

10 **if** $\text{abs}(\text{Xdiff}(n)) < 64$, **then**
 $\text{Xenco}(n) = "010\ s\ \text{xxxx}"$
 $\text{Xdeco}(n) = \text{Xpred}(n) + \text{sign} * (32 + 2 * \text{value})$

15 in which 010 is the code word, s represents the sign, and "xxxx" indicates, in four bits, the value = $(\text{abs}(\text{Xdiff}(n)) - 32) / 2$, the quantizer being 2. For example, when $\text{Xdiff}(n) = 54$ or 55, then the coded value $\text{Xenco}(n) = 010\ 0\ 1011$.

DPCM3:

20 **if** $\text{abs}(\text{Xdiff}(n)) < 128$, **then**
 $\text{Xenco}(n) = "011\ s\ \text{xxxx}"$
 $\text{Xdeco}(n) = \text{Xpred}(n) + \text{sign} * (64 + 4 * \text{value} + 1)$
if $\text{Xdeco}(n) > 1023$, **then** $\text{Xdeco}(n) = 1023$
if $\text{Xdeco}(n) < 0$, **then** $\text{Xdeco}(n) = 0$

25 in which 011 represents the beginning of the code word, s represents the sign, and "xxxx" indicates, in four bits, the value = $(\text{abs}(\text{Xdiff}(n)) - 64) / 4$, the quantizer being 4. For example, when $\text{Xdiff}(n) = -123, -122, -121$, or -120 , then the coded value $\text{Xenco}(n) = 011\ 1\ 1011$.

30 It can be seen that in the last clause, the number one is added to the decoded value, which is due to rounding. When the quantizer is four, it follows that four different values are quantized in the same transmission value. These values are (X), (X+1), (X+2) and (X+3), in which X is an integer divisible by four. To minimize the rounding error, the selected return value should be (X+1.5).
35 However, this is not possible, because the return value must be an integer. Consequently, the best choices are (X+1) and (X+2). By probability, the lower

figures (X) and (X+1) occur slightly more frequently than the higher figures (X+2) and (X+3), because the number of occurrences is always slightly reduced when the difference is increased, as a result of successful operation of the predictor. Because of this argument, (X+1) has been selected as the return value.

If the change is greater than the highest of said limit values (> 127), the PCM codec is used in the advantageous embodiment of the invention (case 1). Thus, the encoded value is not predicted from the preceding value but it is formed of the original pixel value. The change of the encoding method is indicated by a special code word, an escape symbol, which was introduced above in connection with the formation of the code words.

case 1: first embodiment PCM

else

$$\begin{aligned} X_{\text{enco}}(n) &= "1 \text{ xxxxxxxx}" \\ X_{\text{deco}}(n) &= 8 * \text{value} + 4 \end{aligned}$$

in which 1 is the code word indicating a change, "xxxxxxx" indicates, in seven bits, the value $= (X_{\text{orig}}(n) / 8)$, the quantizer being 8. For example, when $X_{\text{diff}}(n) = 520 - 527$, then the encoded bit string is "1 1000001".

The encoded bit string applying the PCM method comprises, as the first bit, the escape symbol code word 1, which has been selected so that more bits can be used for the encoding of the colour value than in DPCM methods. By this arrangement, it is possible to guarantee the image quality, because the bit resolution is reduced gradually more slowly than the number of colours is increased in the different encoding alternatives.

The pixels of the image line are coded in a corresponding manner to the end of the line (EOR), by encoding minor changes by the DPCM method and major changer by the PCM method. Correspondingly, the rest of the lines to the end of the image are processed independently in the same way as the preceding pixel line, wherein the whole image can be compressed.

The superiority of the combination of the DPCM and PCM codecs to the DPCM codec alone is well-founded when the combination is compared with the use of the DPCM codec alone. As an example, a situation (case 2) will be presented, in which the DPCM codec is used for encoding both minor and major changes. With this example, the advantages which are achieved by combining the DPCM method with the PCM method in a way according to the invention, can be better understood by a person skilled in the art. It should be noted that this example is only given to illustrate the advantages of the invention; it has no significance in the implementation of the invention.

case 2: second embodiment
else

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Xenco(n) = "1 s xxxxxx"  
Xdeco(n) = Xpred(n) + sign *(16 * value +7)  
if Xdeco(n) > 1023,      then Xdeco(n) = 1023  
if Xdeco(n) < 0,        then Xdeco(n) = 0
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in which 1 indicates the code word, s represents the sign, and "xxxxxx" indicates, in six bits, the value = $(\text{abs}(\text{Xdiff}(n)) / 16)$, the quantizer being 16. For example, when $\text{Xdiff}(n) = 528 - 543$, then the encoded bit string is "1 0 100001".

It can be seen that the sign bit s "eats" one bit of the value to be quantized, wherein the error with the DPCM codec is greater than with the PCM codec, because the quantizing must be greater. This is because the values to be transferred to the PCM and DPCM codecs are in the ranges [0, 1023] (10 bits) and [-1023, 1023] (11 bits), respectively.

In an advantageous embodiment of the invention, the escape symbol used is the shortest code word "1", as presented above. Although the escape symbol is not the most probable symbol, its choice will result in a situation that the quantizing error is so high that the code word length cannot be increased any further. The impairment in the quality, caused by the longer escape symbol code word, can no longer be restored by reducing the code words of the other symbols and by increasing, for example, the non-quantized range of the more probable symbols. Moreover, it is not worthwhile to implement the processing

of a major change in the DPCM codec, because it will result in the same situation as when the length of the escape symbol was increased in the original solution.

5 It should also be noted that the other symbols than the escape symbol follow the real probability of the symbols. This applies also when the quantizer is greater for greater changes. The length of the code words is based on the quantity of the change in the following way: 1 = change[128—1023], 2=[0—31], 3=[32—63], 3=[64—127]. The lengths are based on the shape of the
10 change distribution after the quantizing error has been eliminated. The number of symbols needed in the DPCM codec is fewer than or equal to $N - (M - 1)$ (for example, $10 - (8 - 1) = 3$). In the DPCM encoding according to the invention, preferably all three of these are used. In the calculation of the maximum number of DPCM characters, the equation is based on the length of
15 the value of the escape symbol, which is $M - 1$ ($8 - 1 = 7$) bits. For the symbols of the DPCM codec, there is thus no substantial need to use greater or equal quantizing as in connection with the PCM codec. Furthermore, it is not necessary to use two different code words for the same quantizer, because the order of code words can thus be changed or two code words can
20 be combined.

By using the method of the invention, the output, in the worst case, is encoded in 7 to 10 bits. In a corresponding situation, the use of the DPCM codec alone will result in an output which is encoded in 6 to 10 bits. By using
25 the method according to the invention, the signal-to-noise ratio PSNR (Peak Signal Noise Ratio) used for measuring the image quality is in the range from 67.48 dB and 78.01 dB. If the PCM codec is replaced with the DPCM codec, the corresponding figure will drop to the range from 63.67 to 74.48 dB.

30 The image quality achieved by the arrangement according to the preceding embodiments of the invention can also be achieved by using a smart DPCM codec (case 3), but this will increase the complexity of the codec, which may be a significant obstacle to using this embodiment of the invention in some environments. In this embodiment of the invention, it has been found that
35 even though the values to be coded are in the range from -1023 to 1023, there are only 1024 different values for the prediction. By the other values, an

Xdeco value is obtained, which is smaller than 0 or greater than 1023. These values will never occur in the original image. Consequently, in connection with major changes, the DPCM codec can be used in a smart way as follows:

5 **case 3: third embodiment**
 else

 Xenco(n) = "1 s xxxxxx"

10 in which 1 indicates the beginning of the code word, s represents the sign, and "xxxxxx" indicates, in six bits, the value = $(\text{abs}(\text{Xdiff}(n)) / 8)$, the quantizer being 8.

15 These high absolute values should be encoded by using values which are not otherwise used in predicting encoding. The example below presents first the change of the range and the decoding.

if value == 64 **then** value = 0
 if value > 64 **then** value = 128 – value, and the sign is changed

20 For example, when $\text{abs}(\text{Xdiff}(n)) = 528 - 543$, then the encoded bit string is "1 1 111110".

25 In the decoding, the following steps are taken:

if value = 0 **then**
 Xdeco(n) = Xpred(n) + sign * (8*64+7)
 else
 Xdeco(n) = Xpred(n) + sign*(8*value)
30 **if** Xdeco(n) < 0, **then**
 Xdeco(n) = Xdeco(n)+1024+3
 but if Xdeco(n) > 1023 **then**
 Xdeco(n) = Xdeco(n) –1024-3
35 **else**
 Xdeco(n) = Xdeco + sign * 3

if $X_{\text{deco}}(n) > 1023$, then $X_{\text{deco}}(n) = 1023$
if $X_{\text{deco}}(n) < 0$, then $X_{\text{deco}}(n) = 0$

5 Figure 1 shows an advantageous example of the encoder, and the corresponding decoder, implementing the method of the invention. The encoder implements the bit conversion from 10 bits to eight bits, and the decoder implements, accordingly, the bit conversion from eight to ten bits. The encoder (Enc) comprises a selector (Sel / Enc) which changes the codec
10 according to magnitude of the change in question. DPCM1 is in use, when $X_{\text{diff}} < 32$, DPCM2 when $X_{\text{diff}} < 64$, DPCM3 when $X_{\text{diff}} < 128$, and else PCM. The encoder also comprises an internal decoder (Dec) to implement the decoding of the symbol for prediction (Pred). For this purpose, the two symbols preceding the symbol to be decoded are stored in a memory (MEM),
15 in decoded form. A similar decoding process is also carried out by the actual decoder (Dec 8 → 10).

Figure 2 shows an advantageous example of the encoder and decoder according to the invention, which are arranged to perform the bit conversion
20 from 10 bits to seven bits and back to ten bits. In the prediction, the predictor of Fig. 2 uses all the colour values in the line (two colours per line in Bayer matrix). The first pixel is encoded without prediction. The second pixel is predicted by using the preceding decoded value as the prediction value: $X_{\text{pred}}(n) = X_{\text{deco}}(n-1)$. The third pixel is predicted by using the preceding
25 decoded value of the same colour as the prediction value: $X_{\text{pred}}(n) = X_{\text{deco}}(n-2)$. The fourth pixel is predicted by using the equation:

If
30 $((X_{\text{deco}}(n-1) \leq X_{\text{deco}}(n-2) \text{ and } X_{\text{deco}}(n-2) \leq X_{\text{deco}}(n-3)) \text{ or } (X_{\text{deco}}(n-1) \geq X_{\text{deco}}(n-2) \text{ and } X_{\text{deco}}(n-2) \geq X_{\text{deco}}(n-3)))$
then $X_{\text{pred}}(n) = X_{\text{deco}}(n-1)$
else $X_{\text{pred}}(n) = X_{\text{deco}}(n-2)$.

35 The other pixels in the line are predicted by using the equation:

if
((Xdeco(n-1) <= Xdeco(n-2) **and** Xdeco(n-2) <= Xdeco(n-3)) **or** (Xdeco(n-1)
>= Xdeco(n-2) **and** Xdeco(n-2) >= Xdeco(n-3)))
then Xpred(n) = Xdeco(n-1)
5
but if
((Xdeco(n-1) <= Xdeco(n-3) **and** Xdeco(n-2) <= Xdeco(n-4)) **or** (Xdeco(n-1)
>= Xdeco(n-3) **and** Xdeco(n-2) >= Xdeco(n-4)))
then Xpred(n) = Xdeco(n-2)
10
else Xpred(n) = (Xdeco(n-2) + Xdeco(n-4) + 1) / 2.

Because the encoder according to the example of Fig. 2 uses four preceding
pixels in the prediction, the memory (Mem) is arranged for four pixels
15 accordingly.

In connection with this bit conversion (10 – 7 – 10), the encoding/decoding is
carried out in a way similar to the conversion from 10 bits to eight bits.
However, it must be noted that the code words used and the ranges
20 corresponding to them follow the definition:

if abs(Xdiff(n)) < 8, then
Xenco = 000 s xxx
the code word is 000, s = sign, xxx = value = abs(Xdiff(n) / 1) given in
25 three bits, the quantizer = 1

if abs(Xdiff(n)) < 16, then
Xenco(n) = "0010 s xx"
the code word is 0010, s = sign, xx = value = (abs(Xdiff(n)) – 8) / 2 given
30 in two bits, the quantizer = 2

if abs(Xdiff(n)) < 32, then
Xenco(n) = "0011 s xx"
the code word is 0011, s = sign, xx = value = ((abs(Xdiff(n)) – 16) / 4,
35 given in two bits, the quantizer = 4

if abs(Xdiff(n)) < 160, then

Xenco(n) = "01 s xxxx"

the code word is 01, s = sign, xxxx = value = (abs(Xdiff(n)) - 32) / 8,
given in two bits, the quantizer = 8.

5

if abs(Xdiff(n)) > 160, then

Xenco(n) = "1 xxxxxx"

the code word is 2, s = sign, xxxxx = value = Xorig(n) / 16 given in six
bits, the quantizer = 16.

10

As it can be seen from the above, five code words are needed in connection
with the bit conversion of the described kind, when four code words are
needed in connection with the bit conversion (10-8-10).

15 Figure 3 shows a very reduced view of a system implementing an
advantageous embodiment of the invention. The system preferably comprises
devices A and B which implement the encoding (Enc) / decoding (Dec)
according to the invention, respectively. The devices A, B can be placed
physically separately in the system. The devices A, B can also be
20 implemented as a single physical unit. Arrangements of the described type,
combining DPCM and PCM modulation or using smart DPCM modulation, can
thus be implemented as part of the electronic device, for example in a digital
signal processing unit (DPS) in a camera or the like. Typically, the electronic
device also comprises other functions, such as means for displaying (D)
25 image information to the user and a processor for controlling the electronic
device. A digital camera (C) comprising an image processing system
according to the invention can be preferably implemented in connection with a
mobile device, either as a separate unit or integrated in the device, which
mobile device also comprises means for mobile communication. Furthermore,
30 the digital camera comprising the image processing system according to the
invention may be connected to a communication network (e.g. the Internet),
such as WebCam. The whole invention can be implemented by using
hardware arrangements, a microcodable processor, or alternatively by
computer software alone. All combinations of these are also possible.
35 Consequently, the invention can typically also be used as a part of larger

software, it can be constructed as part of a separate encoding circuit, or it can be implemented in connection with a camera module to be retailed separately.

5 In the specification, the present invention has been described according to two advantageous embodiments. It is obvious that the above-described different embodiments of the invention can be combined to provide various embodiments of the invention which comply, as such, with the spirit of the invention. Therefore, the above-presented examples must not be interpreted
10 as restrictive to the invention, but the embodiments of the invention can be freely varied within the scope of the inventive features presented in the claims herein below.

What is claimed is: